Distribution of our CoBOP Results: IOPs and Albedo Spectra for Incorporation into Radiative Transfer Models

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LONG-TERM GOALS

The deconvolution, quantification, and interpretation of various components of water-leaving radiance in shallow coastal waters are the long-term goals of the project. This interpretation involves the understanding of how different bottom types affect the underwater light field.

OBJECTIVES

In this project, objectives have included the development of instrumentation and models to measure and predict the contribution of bottom reflectance to upwelling radiance in coastal waters. An underlying objective, then, is the development of the methodologies required to remotely classify bottom types in varying water depths. Intrinsic in this effort are quantifying the optical properties of the water column, and addressing the inherent problems of scale between *in situ* and remotely sensed data. Recently, emphasis has been placed on information extraction and quantification of optical effects of a corrugated ocean bottom (e. g. sand waves) on bathymetry and bottom albedo calculations from water-leaving radiance. Additionally, effort has been expended in utilizing multi-spectral bottom video to build a multi-spectral bottom mosaic that includes 3-dimensional information. Finally, rigorous data validation/calibration is required while working toward optical closure.

APPROACH

During the CoBOP project (1996-2000), transects over coral bottoms in the Dry Tortugas and the Bahamas were laid out and mapped by divers and by the Fluorescence Imaging Laser Line Scanner (FILLS). Instrumentation aboard our Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) platforms were used to determine the color and intensity of bottom elements from different altitudes (Costello et al., 1997: Englih et al. 2002). The goal was to correct imagery for path radiance and attenuation, providing bottom albedo estimates for the dominant bottom types/features, to image bottom fluorescence, and to measure the vertical spectral structure of the upwelling and downwelling light fields. The analyses required rigorous validation, calibration, and modeling efforts.

During the year, effort was expended toward utilizing the archived imagery and ancillary data, developing relatively low-cost methods that could exploit gross bottom reflectance signatures to yield useful data.

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14. ABSTRACT
The deconvolution, quantification, and interpretation of various components of water-leaving radiance in shallow coastal waters are the long-term goals of the project. This interpretation involves the understanding of how different bottom types affect the underwater light field.

15. SUBJECT TERMS

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WORK COMPLETED

- A method has been developed, based entirely on scene content, to create mosaics of along-track bottom imagery from underwater vehicles with automated correction for bathymetry and vehicle motion (see RESULTS).
- A method to quantify the spectral effects of bottom texture (i.e. sand waves) on retrieval products of remote sensing (bottom albedo and depth) has been developed (Carder et al. 2003).
- A method which utilized color video taken from the OV-II AUV to calculate the percent live sea-bottom cover (Renadette et. al., 1997, 1998; Hou et. al., 1999) has been extended to multi-spectral imagery (Hou et al., 2002; English et al. 2002).
- Application of the bi-static, laser-line imager ROBOT provided 3-D measures of sand waves, stromatolites, grass beds, and mine simulants (Carder et al. 2001, 2003).

RESULTS

- Bottom texture (i.e. sandwaves) can spectrally alter upwelling radiance as a function of sun angle due to the spectral difference between diffuse and collimated solar illumination (Carder et al. 2003). Aircraft images were collected near Lee Stocking Island (LSI), Bahamas with wave-like features for bright sand bottoms during times when solar zenith angles were large. The image contrast between leading and trailing sand-wave facets approached a 10-15% difference due to algae accumulations in wave troughs or topographic variations of the bottom. Reflectance contrast for blue light was greater than for red and green wavelengths when algae or detritus is present in the troughs. However, the contrast at green and red wavelengths was greater than at blue wavelengths when caused by the interplay between bottom topography and oblique illumination.
- Hyperspectral remote-sensing reflectance data collected using an undulating autonomous underwater vehicle (AUV) was utilized to determine the diffuse attenuation and absorption coefficients of the water column and the bottom albedo (English et al. 2002). The method was robust under cloudy and partly cloudy conditions.
- Data collected by our group was used (Voss et al. 2003) to help explain the scene bi-directional distribution functions (BRDF) as opposed to near-bottom (sediment) BRDF.
- An advanced heat-budget model for shallow evaporitic environments uses outputs from bottom and optical properties collected during CoBOP (Warrior et al. 2002). His dissertation work extends this research with the Princeton Ocean Model (POM) to explain the outflow and sinking of dense, hypersaline features found down to 40m in Exuma Sound.
- The shallow environments modeled by Warrior et al. provide waters rich both in CDOM and salt to the Exuma Sound as viewed using SeaWiFS (Otis et al. 2002, 2004). The water exported after daily solar heating remains at the surface and can be carried far offshore by southerly winds. The water exported after nocturnal cooling is heavier and sinks to form the saline plumes observed by Hickey et al. (2001).
- Efforts have been made to create large-scale mosaic images from individual video frames obtained with a multi-channel, intensified video camera (Xybion IMC-301, 6 channels) onboard the autonomous underwater vehicle (AUV) ROVEX during the CoBOP 2000 field campaign. The large-footprint (3.5 by 36 meters), pseudo-colored mosaic created will not only help to identify targets on the ocean floor, but could also provide detailed stereographic bathymetric information over the sampled area. This effort is discussed below.

Video mosaic
An approach entirely based on scene-content tracking is used to automatically piece together the continuous mosaics for each of three, narrow-band video channels (460, 520 and 575nm) using best estimates from each of the channels to identify vehicle movement. The results from 3,500 consecutive frames (Figs. 1 through 3) represent a spur-and-grove coral region approximately 3.5x36 m^2 near Lee Stocking Island, Bahamas.

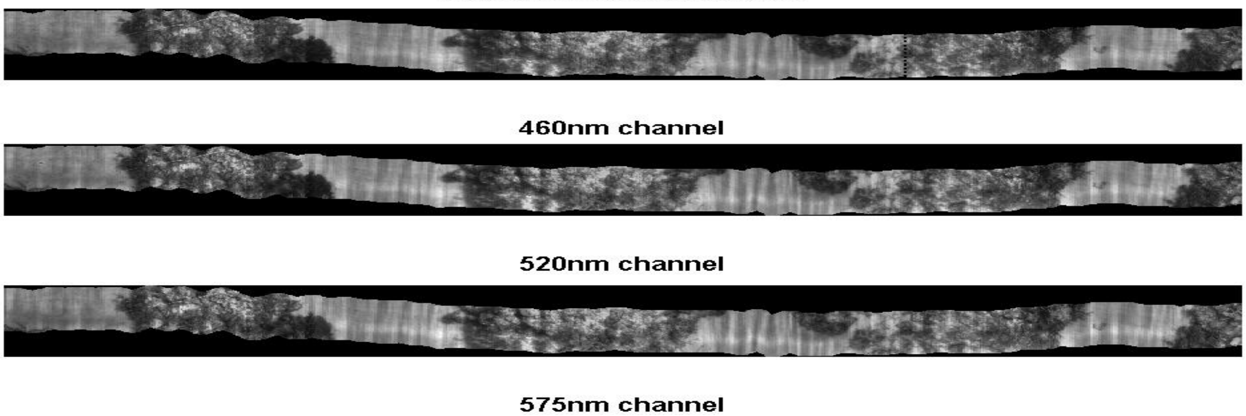

Figure 1. Mosaic created with 35000 consecutive video frames, covering approximately 3.5 by 36 meters. The ROVEX deployment was at Lee Stocking Island during the CoBOP 2000 field

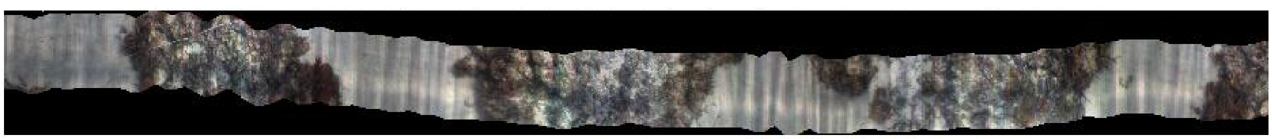

Figure 2. Color composite of multi-channel mosaics.

Bathymetry
Bathymetry over complicated bottom features is difficult to retrieve, especially in coral-reef areas. Even precision acoustic altimeters, for example, send energy through a relatively wide conic volume and the resulting returns are confused due to the complex topography of the reef. In a stereoscopic approach (Zhu etc al. 1999), the relative altitude of the vehicle is obtained by comparing relative feature displacement between consecutive scenes for each channel. An initial attempt is made by examining a small (50x50) window of relative movement compared to the vehicle movement (whole scene). Assuming a constant speed for the vehicle, the estimated speed variations of the small window is directly proportional to the elevation of the vehicle over ground, or altitude. Figure 4 compares the measured altitude versus the estimate by this approach. The three coral-reef clusters are clearly represented in both techniques although it is currently unclear why the position estimates of the patches vary between techniques. Further work, including spectral analysis and examination of the fluorescence band, is underway.

Wave focusing
The vertical stripes shown in the mosaic (Fig. 5, bottom) are probably caused by wave focusing. Wave focusing/defocusing would result in relatively higher/lower camera exposure times which is apparent in the plot of the exposure times for individual frames from all three channels (Fig. 5, top). The wave

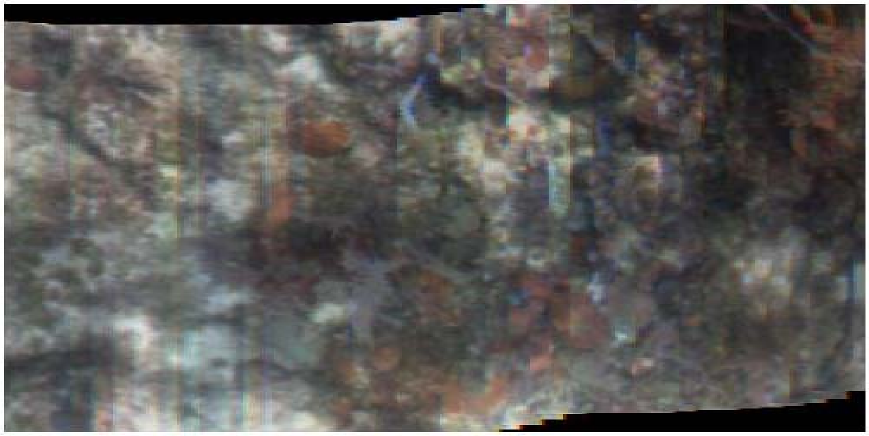

Figure 3. Detail of a small segment of the pseudo-color mosaic of Figure 2. This scene covers approximately 3.5 by 6 meters. Individual soft and hard corals are evident.

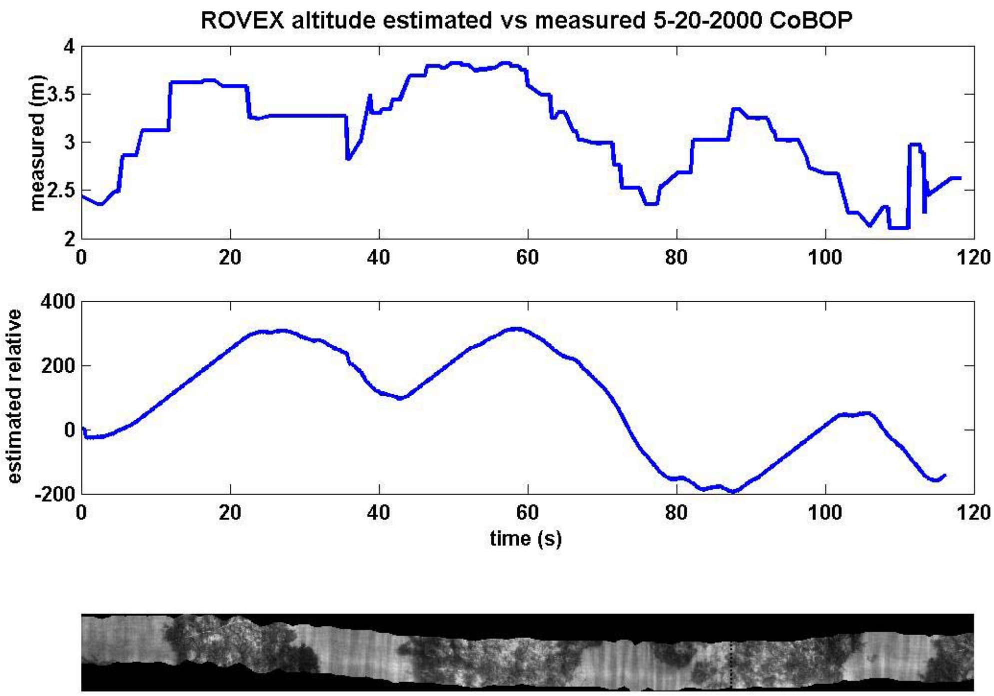

Figure 4. Altitude measured by an acoustic altimeter (top) and estimated by relative movement inside the scene (middle). The scene is shown at the bottom of the figure. The two techniques both measure the three large coral patches but are not consistent in the precise locations of the patches.

focusing is the high-frequency component of the data and is more obvious when the vehicle is cruising over bright, sandy areas (lower exposure times). The period is about 2-seconds on average. With the vehicle moving at approximately 1 m/s, the estimated wave speed at about 3 m/s and the alternating light and dark regions are recorded by the camera producing the stripes shown. Since this is caused by the variation of the light field, correcting for exposure times and camera gain will not remove the effects. To remove these effects, one could use recorded exposure times and average the same sub-scenes that are collected half a period apart, effectively compensating brighter (focused) regions with darker (de-focused) regions.

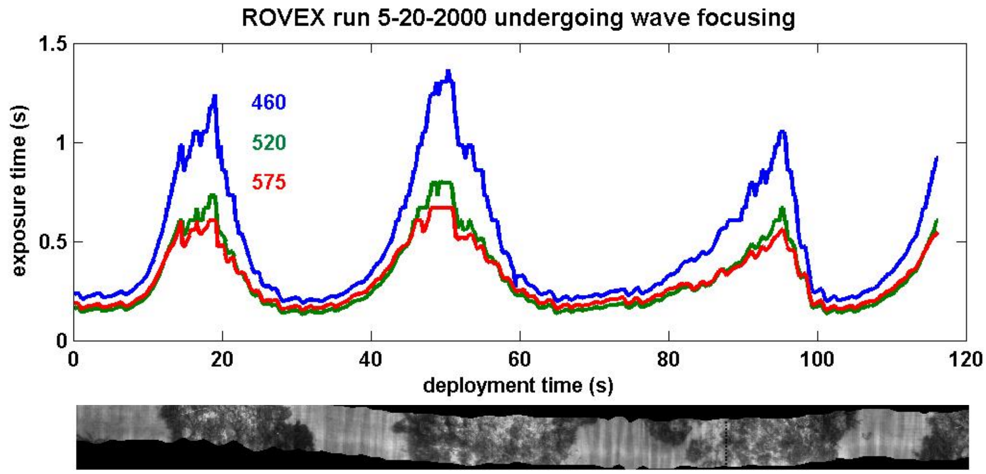

Figure 5. Wave focusing causes vertical stripes in a large scale video mosaic.

IMPACT/APPLICATIONS

This work improves AUV and aircraft remote-sensing algorithms for bathymetry and bottom albedos. Improved heat- and salt-transport models, and understanding of CDOM source and delivery mechanisms also derive from this research. Additionally, methods developed for utilizing AUVs in large-area surveys of the bottom albedo for use in bottom classification and heat and light models appear feasible for validating interpretations of aircraft and spacecraft imagery.

RELATED PROJECTS

As part of the CoBOP Directed Research Initiative, this project is synergistic with numerous other CoBOP investigations and several multi-discipline investigations have been completed. This project also provides significant data to and benefits from important instrumentation developed under "Optical Variability and Bottom Classification in Turbid Water: Phase III" (Carder and Costello, ONR CODE 3220M).

Our field data are being utilized in the effort "Hybrid Modular Optical Model To Predict 2-D and 3-D Environments in Ports…" (HyMOM, ONR, Reinersman and Carder) to model the structure of the underwater light field around objects (e.g. ship and seawall shadows) under various environmental conditions

We are investigating the efficacy of different stimulation wavelength and sources in active fluorescence imagery and identification of bottom objects. This work is in conjunction with Charles Mazel, Physical Sciences, Inc.

Efforts within our group toward model inversion (funded through ONR/CoBOP and NASA) utilizing remote sensing reflectance provides bathymetry and water optical properties. Most recently, efforts have been focused on providing sea truth and image interpretation for the PHILLS hyperspectral imaging sensor owned and operated by NRL Washington (Curtiss Davis).

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